Providing a Progression of Immersive Visualization Technologies

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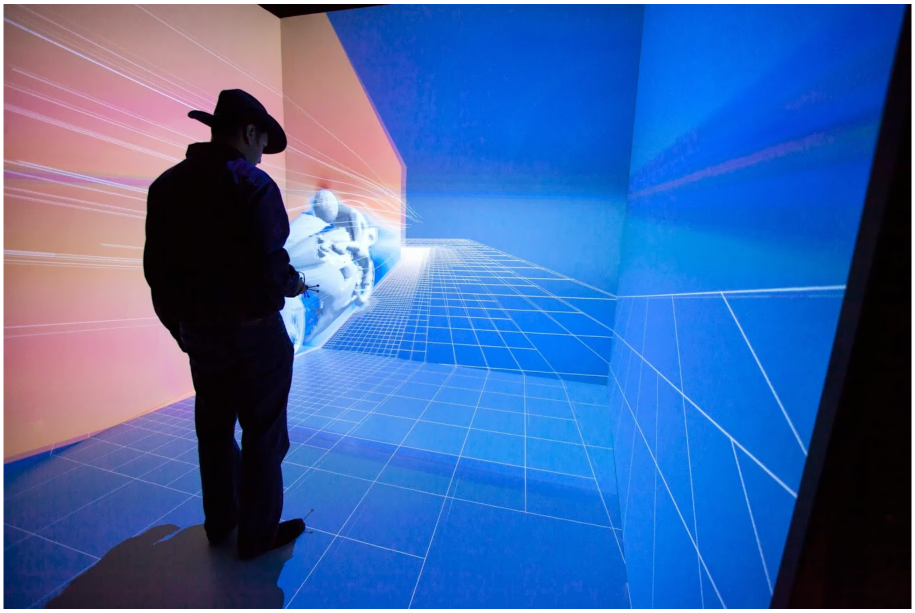

Fig. 1. *Cowboy in a CAVE*, ParaView streamline visualization in the Shell 3-D Visualization Laboratory, School of Energy Resources, University of Wyoming (photo by bhp imaging).

Abstract—Large-scale visualization technologies provide added visual benefits for visualizations, such as increased resolution, the computational facilities to handle data at scale, and, in the case of immersive visualization, depth information or motion cues provided by head-tracking. However, adoption of large-scale visualization technologies is impeded by several factors including: location, software, ease of use, and integration into existing workflows. We believe that these barriers can be addressed by providing a progression of visualization technologies that span from laboratories, conference rooms, to lecture halls, and draw researchers into a large-scale visualization technology. In this paper, we discuss the implementation of such a progression environment for immersive visualization technologies implemented at UW's SER immersive visualization facilities.

Index Terms—Immersive visualization environments, virtual reality, energy resources

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1 INTRODUCTION

In the Fall of 2010, the authors were approached to design, develop and deliver advanced visualization environments for the University of Wyoming's Energy Innovation Center (EIC)[1]. This state-of-the-art research and collaboration facility opened in January 2013 to support the University of Wyoming (UW) and the School of Energy Resources (SER) in achieving the mission of positioning Wyoming as a global leader in energy education, research, and outreach. The EIC, located on the northwest corner of UW's Laramie campus, includes 56,941 square feet of highly technical research space, as well as office, classroom, and meeting space. Approximately 12,500 square feet of the EIC is designated for six rapidly reconfigurable, modern laboratory spaces that play a key role in advancing SERs strategic areas of concentration.

As one of the most advanced research facilities at the university, the EIC provides students, researchers, and academic professionals the opportunity to actively engage in, observe, and support advancements in sustainable energy technologies.

After touring several industry, national laboratory and university facilities, the Director of SER, and the scientists and engineers leading SERs strategic areas of concentration, settled on a facility leveraging primarily immersive visualization environments (IVEs). IVEs are, in fact, virtual reality environments focused on the application of VR technologies for scientific and information analysis and visualization. There is a specific emphasis on physical immersion to more fully engage the perceptual and kinesthetic capabilities of the scientist, engineer, and medical researchers with the goal of enabling greater insights.

VR has been hyped, by inflated expectations, as the wave of the

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[1] The design and construction of the $25.4 million EIC was made possible through private donations and State of Wyoming matching funds. Encana provided the largest private donation for the building with a $5 million commitment in 2007 that was matched by the state. Generous private donations were also given by BP, Shell, Peabody Energy, Arch Coal, Marathon Oil, Questar, and ConocoPhillips.

future. Our goal was to meet UW's more realistic expectations, and avoid the trough of disillusion, where these facilities are portrayed as goofy and expensive.

2 DESIGN

Adoption of large-scale visualization technologies is impeded by several factors including: location, software, ease of use, and integration into existing workflows. We strategically developed our design based on answering the following questions.

What would drive the faculty, staff, and students to move to the next room, the next floor, the next building, or across campus? For large-scale visualization technology, there is generally very little that can be done with regards to location. The hope is always that making these systems sufficiently enticing is enough, but, without a plan to address the location issue, these facilities all to often become widely used by the organization's tour personnel and narrowly used by the few hardy researchers.

Fig. 2. The BP Collaboration Conference room prepared for a reservoir simulation group meeting.

For UW's SER advanced visualization environments, our plan was to sacrifice the size and/or capability of the single large-scale visualization technology, to place a number of smaller-scale systems where the researchers work, such as conference rooms and lecture halls.

Fig. 3. The Encana Auditorium displaying iron protein with ParaView to be used in a class.

In the BP Collaboration Center conference room, we deployed a three by two matrix three-dimensional capable tile wall from Planar with Advanced Realtime Tracking (ART) tracking system for interaction based on our previous work with IQ-Walls [5]. When not utilized as an IVE, the tile wall serves as a two-dimensional tile wall for scientific visualization or an external monitor for displaying information and presentations from a number of video sources. This facilitates small groups of researchers to explore immersive visualization in an environment they have previously integrated into their workflows (*the conference room*).

The Encana Auditorium/Lecture Hall is outfitted with the same three by two matrix three-dimensional capable tile wall, making it easy to move from small research group meetings in a conference room, to larger research groups meeting in an auditorium or lecture hall.

In addition, we specifically purchased a portable, laboratory-sized IVE so that the technology could be wheeled into their work rooms and laboratories based on our work with the IQ-Station [3]. The Mechdyne three Planar screen portable "mini-cave" visualization system is compatible with a number of unique sized work rooms and laboratories. It can open up into a three panel three-dimensional tile wall or close-in to environment that emulates a CAVE$^{\text{TM}}$.

Fig. 4. The Mechdyne "mini-cave" folded out in a laboratory.

Is our software available in these environments? For all systems, we developed an inclusive software stack through consultation with UW's SER research community [6].

First, we made all systems switchable between Linux & MS-Windows, not simply dual-boot. Second, we reserved plenty of funds to purchase commercial software embedded in the researchers current workflows(Avizo, Conduit, ESRI, Petrel/Eclipse, AutoDesk, NuGraph, Google Earth, etc.). In addition, we purchased software development hours from Mechdyne to port non-immersive applications to use Conduit. Finally, we leveraged our Bootcamp open-source software suite based on VR libraries Vrui and FreeVR (Visualizer3D, LidarViewer, Toirt Samhlaigh, VRProteinShop, VMD). While ParaView VR does not link to a VR rendering library, for 6-DOF position tracking data it makes use of either (or both) the VRPN input library or the Vrui system's input device daemon.

Not surprising to the authors, ParaView, Visit, Avizo and Petrel make up nearly 100% of the software usage.

How do we lower the learning curve (ease of use) for using IVEs? With limited recurring funds, we chose to initially staff only two of "*three skinny guys*" [1]. From Mechdyne, we subcontracted a *skinny guy* for onsite system support to keep all the systems operating as expected, and to provide hands-on support for how to operate the systems. From Kitware Inc., we subcontracted, and subsequently hired, a software engineer for visualization research support. This *skinny guy* helps the researchers move their data into existing applications in the IVE, and specifically not developing new applications. These two staff positions are completely focused on supporting researchers in utilizing the systems and software stacks as is.

Staffing is a recurring cost. By using contractors, we were able to keep costs down while finding qualified individuals in a very small niche area of computer science.

In our view, the third skinny guy, providing visualization research and new software development, requires a significant critical mass to be effective and efficient, and an investment at this stage is premature. Instead, we focused on positioning UW's SER advanced visualization facilities to be part of a national/international immersive visualization community development effort.

How do we seamlessly transfer what we do on our desktops/laptops into these facilities? Or how do we enhance, but not disrupt our scientific and engineering workflows? Our plan is to offer a well defined, by the researchers themselves, software stack and implement it in all of the IVEs. Then, utilizing the two *support* skinny guys, integrate these resources into each research group's workflow, a group at a time.

Is there value added to our research when applying immersive techniques? Definitely. The need for more natural and effective interfaces for immersive environments is real and growing. As described in the

2006 NIH/NSF report [2] on visualization research challenges, Fluid interaction requires that we create user interfaces that are less visible to the user, create fewer disruptive distractions, and allow faster interaction without sacrificing robustness. What Johnson et al. were calling for is in fact the essence of IVEs. This is the missing link that immersive environments provide. This need was echoed in an NSF sponsored workshop [4] by presenters and attendees alike.

Our plan is to provide access to low-cost (sometimes portable) hardware, domain-specific capable immersive visualization software, and the integration of both into existing scientific and engineering workflows. We believe this will be enough to draw the researchers in to the easy-to-use large-scale visualization technologies. In addition, the large-scale visualization technologies must provide a significant increase in quality experience and resolution of the visuals, or the research teams may determine that there is essentially nothing gained by moving to these facilities.

The Shell 3-D Visualization research laboratory, provides a Mechdyne four-sided, ten foot cube, HD by HD projected CAVE$^{\text{TM}}$-like system which is connected via 10-gigabit lines to some of the most powerful supercomputers in the region, Yellowstone, at the Wyoming National Center for Atmospheric Research Supercomputing Center (NWSC) and UW's Advanced Research Computing Center (ARCC). The size, resolution and computing capability clearly differentiates UW's SER large-scale visualization technologies from those employed in the conference rooms, lecture halls and laboratories.

Fig. 5. The Mechdyne HDxHD CAVE$^{\text{TM}}$using Toirt Samhlaigh and a 2D transfer function to explore the visible male data set at a recent bootcamp.

In addition, the Shell 3-D Visualization research laboratory is outfitted with the same three by two matrix three-dimensional capable tile wall as the conference rooms and lecture halls to provide a smooth transition.

How do we measure return on investment(ROI)? It wouldn't belong until the facilities had to justify existence. Space and recurring costs are always in limited supply. We wanted to change the way the utility was measured in these type of facilities. Typically, the *hours of use* are kept. If the systems are well used, then systems are of value. However, time doesnt equate to value. Five minutes in a CAVE$^{\text{TM}}$may be equivalent to twenty hours at a desktop. Additionally, the first modification to the use metric, by some individuals, is separating dog and pony shows (or tours) from actual research. At a university (and to some extent less at other laboratories), both communication and research should be valued equally.

Our metrics for ROI are

- Are we discovering and/or innovating faster that measures time to science or solution?, and
- Are we able to better communicate important research to our colleagues, students, and the greater university community?

We will capture these events by using social media to blog or tweet both discovery and dissemination activities associated with the IVEs.

2.1 Results

2.1.1 Developing Subsurface Simulators

> *Our group uses UW's SER immersive visualization facilities to enable simulation visualization, interpretation, and collaboration with peer scientists.* (Dr. Ye Zhang)

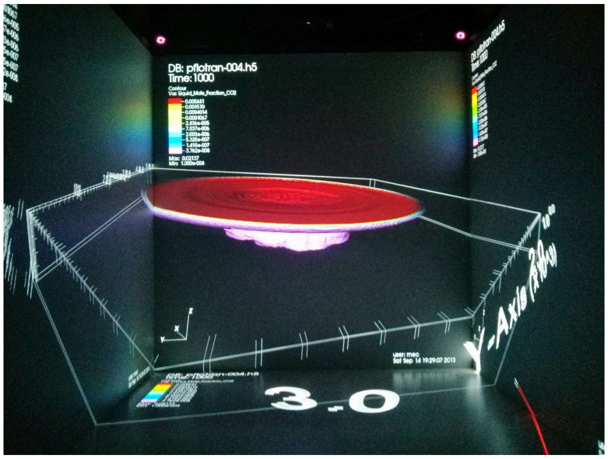

Fig. 6. Visit using Conduit displaying liquid mole-fraction of CO2.

Developing optimal, accurate, and efficient subsurface reservoir models to simulate fluid flow regimes including groundwater aquifers, oil/gas reservoirs, and waste disposal sites is complicated. An important component of Dr. Zhang's research is to employ scientific visualization and data analysis to interpret simulation results in three-dimensions and over time. The unparalleled experience in exploring both the simulation results and field data in an immersive environment is a powerful tool that enables our better understanding the results, which, in turn, spurs new research ideas.

2.1.2 Modeling and Simulation Work at the Enhanced Oil Recovery Institute (EORI)

> *UW's SER immersive visualization facilities are providing a glimpse of where oil still remains in subterranean oil reservoirs after decades of production.*
> (Dr. Shaochang Wo)

In Wyoming, the average oil field has been in play for more than 40 years. For assessing an old oil field and its enhanced oil recovery (EOR)/ in situ oil recovery (IOR) options, reservoir modeling and simulation typically consists of three phases: integrating various static and dynamic data into a simulation model; predicting present oil, gas and water distributions via history matching; and forecasting and evaluating the performance of alternative EOR/IOR floods. At each phase, a good visualization tool increases workflow productivity and enables geologists, reservoir engineers and modelers to contribute to a shared vision in complex reservoirs.

The EOR/IOR technologies most applicable to Wyoming oil reservoirs are waterflooding, polymer-enhanced waterflooding, surfactant flooding, steamflooding, and CO2 flooding. EORI's long-term goal is to utilize these facilities to assist Wyoming operators in making the best possible decision among various EOR/IOR options.

2.1.3 Interfacial and Pore-Scale Transport in Porous Media

> *Every aspect of the molecule or porous media is around you. Unlike our workflow on the desktop, when we zoom in or focus on one aspect of the data we do not loose other aspects in return.* (Dr. Mohammad Sedghi)

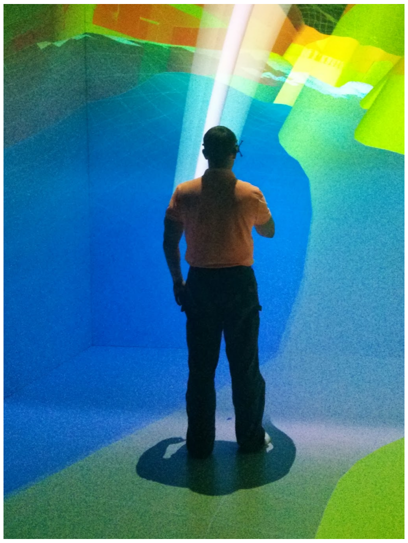

Fig. 7. Petrel using Conduit displaying reservoir simulation results.

In Dr. Mohammad Piri's laboratory, they study the physics of multiphase flow in porous media. The particular porous media they focus on are reservoir rocks, rock formations, shale etc. The rocks are studied at different scales from micro scale to centimeter scale. Their scanning technologies range from medical CT to micro-nano CT to Focus Ion Beam Scanning Electron Microscope (FIB/SEM). They run flow experiments both numerically and experimentally, and these results are compared for validation and verification. UW's SER immersive visualization facilities are currently used to study both numerical and experimental results. In addition, Dr. Piri's group is also working on Molecular Dynamics for flow in nano pores or nano channels.

Fig. 8. Avizo visualizing a pore-scale network.

2.1.4 3D Interaction and Agents

> *It is not enough to investigate interaction isolated in our research laboratory. We must work with domain scientists, real data, and evaluate our techniques using the actual systems stakeholders with the software they will be using to explore and analyze their data.*
>
> (Dr. Amy Ulinski Banic)

Although immersive systems provide added visual benefits for visualizations, such as depth information or motion cues provided by head-tracking, additional interaction challenges are introduced due to added degrees of freedom, perception issues, size of and proximity to display, etc. Furthermore, simulations and visualizations reaching petascale and exascale heavily rely on high performance computing (HPC), however input/output and data movement constraints further cripple interaction capabilities and as a result decrease scientific workflow efficiency.

UW's SER immersive visualization facilities allows the 3DIA laboratory to investigate, design, develop, and test novel software and hardware interaction solutions that will facilitate energy domain scientists to more effectively and efficiently explore and analyze their data.

Fig. 9. VRProteinShop using gloves for interaction.

3 CONCLUSION

Since UW's SER immersive visualization facilities came online in the Spring of 2013, it's too early to report significant impact on SER's research. It will take years to pass before we can measure any long-term impacts, where we might report increased adoption by scientists and engineers, or journal articles that were the direct result of the use these IVEs. However, there is a plan in place that will carry the School's facilities past the typical first refresh hurdle, and there are indications that significant impacts on SER's strategic areas of concentration are on the horizon in the near-future.

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